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TESTING FOR CONSTRUCTION AND EVALUATION OF AIRPORT PAVEMENTS

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TESTING FOR CONSTRUCTION AND EVALUATION OF AIRPORT PAVEMENTS

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INTRODUCTION

The strength and durability of airport pavements may vary widely depending on the materials and methods used in their construction. The tremendous increase in the size and weight of aircraft during recent years and the continuing need for safety and economy has focused attention on the necessity for the development of adequate data in connection with the properties and behavior of such materials. This paper describes investigational methods and procedures employed by the Corps of Engineers in connection with the design, construction, and evaluation of airport pavements in the zone of the interior.

Organization of Test Facilities

Specialized organizations under the supervision of Waterways Experiment Station, Vicksburg, Mississippi, and the Ohio River Division, Cincinnati, Ohio, are delegated primary responsibility for conducting broad investigational programs of a general nature, and the development and standardization of methods and procedures. From time to time, specific research problems, such as the effect of frost penetration, may be delegated to other Divisions. Approved recommendations are incorporated in official manuals[3] and Guide Specifications.

Investigational and acceptance tests are performed by Division Laboratories which are established in strategic locations with respect to area and volume of work. These organizations are equipped and staffed to perform tests and analyses of considerable complexity. As previously mentioned, they may be delegated responsibility for the solution of specific research problems. Their primary function, however, is the development of factual data in connection with specific projects in order that a safe and economical design may be obtained.

Construction control tests are performed at project laboratories. Since facilities are usually limited, the tests are relatively simple. They provide, however, rapid determination of certain properties of the raw materials and finished product which either directly or indirectly indicate the degree of variation from specification requirements or design criteria. Significant varia-

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3. Chapters 1-7, Part XII, Engineering Manual for Military Construction, "Airfield Pavement Design," Corps of Engineers, Department of the Army.

tions form the basis for corrective action or remedial measures. From time to time, selected samples or specimens are forwarded to the Division Laboratory for check purposes and for the performance of pertinent tests for which facilities are not available in the project laboratories.

General. The properties desired in soils for foundations on airfields and for base courses under flexible pavements are: adequate strength, ease of compaction, adequate drainage, resistance to frost action in areas where frost is a factor, and acceptable compression and expansion characteristics. Site selection involves consideration of many factors and, except in rare instances, cannot be made solely on the basis of foundation conditions. Certain of the above properties, if inadequate, may be improved by proper design and construction methods. For instance, materials having good drainage characteristics are desirable, but if such materials are not available locally, adequate drainage may be obtained by installing a properly designed water collecting system. Low strengths in subgrade materials may be compensated for in many cases by increasing the thickness of overlying concrete pavement or of higher quality base materials in flexible pavement construction. Adequate information concerning the characteristics of foundation and base course materials is an essential requirement for intelligent design of airfield pavements.

Preliminary Investigation. Techniques have been developed whereby aerial photographs can be used for the determination of surface drainage patterns and the delineation of areas having similar soil conditions. These methods, together with data provided by geological and agricultural soil maps are often useful in establishing a general picture of the subgrade conditions. More specific information is obtained by field reconnaissance.

The next step in the determination of subgrade conditions generally consists of auger borings located at strategic points. The purpose of these is the development of the soil profile and the selection of representative types of materials for detailed tests. The required number and spacing of these borings is a matter of engineering judgement based on the degree of variation in types and stratification observed. Borings are made to a depth not less than the maximum depth of frost penetration nor less than six feet below the grade line of the top of the subgrade where a cut is contemplated. Borings in proposed borrow areas should be carried two to four feet below the depth of anticipated borrow. Data concerning the location of ledge rock and the depth to water table should also be obtained. Samples are then classified, or placed in groups having similar engineering properties. Classification may be accomplished with some degree of success by means of visual examination and simple field tests. More positive information is provided by laboratory tests for grain size distribution and plasticity characteristics.[4] Soil classification methods and procedures are shown in Figure 1. A soil having particle distribution such that 50% or more is retained on the 200 mesh sieve is coarse-grained. This group is further subdivided according to the predominance of gravel or sand sizes and the amount and character of finer sizes if present in quantities of 5% or more. A special classification system has been devised for the evaluation of potential effects of frost action. Under proper conditions of temperature and moisture, ice lenses will form in soils having a grain size distribution such that 3% or more of its particles are finer than 0.02 mm. The detrimental

4. Part 3, ASTM Standards 1952, American Society for Testing Materials.

effects of frost action are more fully discussed in pertinent manuals.[3] If the particle size distribution is such that more than 50% passes the 200 mesh sieve, the soil is fine-grained (predominantly silt or clay). Plasticity characteristics determined the dominant constituent and provide the basis for further subdivision. Figure 2 indicates the general characteristics of each of the coarse and fine-grained groups and provides a range of soil properties which may be expected with respect to their use as subgrade or base material under airport pavements. A detailed discussion of the classification system described above has been published.[5]

With the aid of the information developed in the preliminary investigation, soil profiles are prepared, and representative types of materials are selected for detailed testing.

Primary Investigations. Experience has shown that it is necessary to compact subgrade soils to relatively high densities to prevent detrimental action under the traffic of heavy wheel loads. Experience has also shown that these densities can be obtained with the proper equipment and procedures. Criteria have been established with respect to the required degree of compaction (expressed as a percentage of a stated maximum). The tests performed in this phase of the investigation are for the purpose of establishing these maximum values and determining relationships of moisture content, density, and shear resistance or supporting power.

The laboratory compaction test is performed for the purpose of determining the maximum unit weight which can be obtained practicably in the field. In the majority of cases, the modified American Association of State Highway Officials (AASHO) compaction test is satisfactory for control purposes. This method is a modification of the Standard AASHO Method T-99-49[6] (often termed the Proctor Control Method). Modifications made by the Corps of Engineers were primarily for the purpose of increasing the compactive effort to obtain higher densities and to provide methods for determining the effect of gravel when present in considerable proportions. For most soils, this test provides an indication of the compaction or densification which may be obtained in the field. It is not applicable to certain types of soils such as those containing high percentages of mica or having particles which are brittle and subject to fracture under moderate impact. In such cases, test sections are required to develop compaction characteristics. Test sections are also useful for the determination of the relative efficiency of various types of rolling equipment.

The California Bearing Ratio Test is employed to obtain a modulus of shearing resistance of a soil under varying conditions of moisture and density. The designer selects CBR values for each type of material based on the conditions ultimately to be expected and determines the required thickness of flexible pavement and base for a given wheel load from standard nomographic charts that have been prepared using information obtained from exhaustive test track experimentation and service records of pavements previously constructed. The CBR method of design is empirical. The Corps of Engineers believes, however, that this method, as presently developed, and when properly applied, is reasonable and satisfactory for the design of military airport pavements. The apparatus used in the performance of the modified compaction and CBR tests are shown in Figure 3. A comprehensive discussion of procedures involved

5. Technical Manual 3-357, "Unified Soil Classification System," Waterways Experiment Station, Corps of Engineers, U.S. Army.
6. "Standard Specifications for Highway Materials and Methods of Sampling and Testing," American Association of State Highway Officials.

in the performance of these tests and their application to the design of flexible pavements has been previously published.[7]

The structural design of rigid pavements for airports depends primarily on the flexural strength of the concrete slab and the resistance of the soil, whether natural or stabilized, to withstand permanent deformation under given stress conditions. The stress from a given wheel load depends upon the sharpness of the deflection curvature of the slab caused by the wheel load bending moment, which in turn is determined by the thickness of the slab and the combined elastic properties of both the concrete and the soil. The modulus of soil reaction is a measure of the latter. It is defined as the load in pounds per square inch at the surface of the soil required to cause a vertical deformation of one inch in the subgrade. As this value increases, a given wheel load produces a smaller tensile stress in the slab. The elastic properties of the concrete, however, are the predominant factors, and the modulus of soil reaction is a minor influence in the determination of the thickness of a concrete slab required to support a given wheel load. Therefore, it is only necessary to bracket this value rather than to fix its absolute value. However, the majority of soils exhibit a marked reduction in the modulus of soil reaction with increase in moisture content. Conditions of moisture, density, and type of material all enter into the interpretation of test results in order to give a design value which will represent the condition of equilibrium that ultimately will obtain. The field bearing test is employed for the determination of the modulus of subgrade reaction. This must be performed on the subgrade or (for fill sections) on test embankments. Briefly, the test consists of determining the settlement of a rigid circular plate 30 inches in diameter on application of a unit pressure of 10 lbs. per square inch (Fig. 4). The subgrade reaction is the ratio of pressure to settlement expressed as pounds per square inch per inch. Except for subgrades composed of coarse granular materials, supporting power is a function of moisture content. When anticipated moisture conditions are more critical than those obtaining during the test, a correction factor is applied. Laboratory consolidation tests are performed upon representative specimens of undisturbed samples of the subgrade. One specimen is tested at its field moisture content, and another after saturation in the consolidation device. Deformations are determined at unit loads of 10 psi. The ratio of deformations is the correction factor to be applied. Detailed procedures for the performance of these tests are found in Chapter 3, Engineering Manual, "Airfield Pavement Design".[3]

Bituminous Testing for Design

General. The function of a bituminous pavement is to provide a resilient, waterproof, load-distributing medium to protect the base course from the detrimental effect of water and abrasive action of traffic. The flexibility of bituminous pavement permits slight adjustments, owing to consolidation of base course or effect of load, without detrimental effect. In planning the composition of bituminous mixtures, consideration must be given to the durability, stability, surface texture, and bitumen content of the resulting pavement. Durability involves resistance to wear and weathering and is dependent largely on the imperviousness of the surface course, the amount and quality of the bitumen,

7. Paper No. 2406, Symposium, "Development of CBR Flexible Pavement Design Method for Airfields," Transactions ASCE, Vol. 115, 1950.

and the quality of the aggregates. The stability of a pavement is its resistance to displacement under loads and is dependent upon the cohesion of the bitumen and internal friction values of the compacted mixture. A desirable surface texture is one free from projecting aggregates and surface voids and is smooth but not slick. The bitumen content is extremely important since it affects the stability and durability of the pavement. Pavements which have too little bitumen will not be durable and those which have too much will rut and shove under traffic. Pavements intended for use by aircraft equipped with high pressure tires and jet motors are carefully designed to produce a structure that will have sufficient stability to resist the stresses imposed by tire pressures of 200 pounds per square inch, a surface texture that will be smooth enough to disperse any spilled fuel, and a density that will inhibit the infiltration of jet fuel into the pavement. Detailed procedures for tests in connection with the design and construction of bituminous pavements may be found in Appendix D, Chapter 2, Engineering Manual, "Airfield Pavement Design".[3]

Materials Survey and Acceptance Tests. A survey of economical aggregate sources to determine the availability of suitable quantities for construction of the pavement is the first step in the design of paving mixtures. The materials normally required for the paving mix are coarse aggregate, fine aggregate, mineral filler, and asphalt cement. In order to obtain and control the desired qualities of a mix, two or more fine aggregates are usually required. Aggregates which are angular in shape generally provide more stable pavements than aggregates of rounded shape. Acceptance tests are then performed on representative samples of these materials.

The normal tests performed on aggregates are sieve analysis, specific gravity, abrasion, swell and stripping. From grading curves, an experienced engineer can obtain general information concerning the suitability of the aggregates, the quantity of bitumen required and whether the addition of mineral filler is required. Specific gravity of aggregates used in the computation of percent total voids and percent voids filled should approximate the realistic specific gravity, which varies with different aggregates from dry bulk to apparent, of the aggregates impregnated with asphalt under field conditions. The Corps of Engineers is in the process of developing a test procedure for determining this specific gravity. The abrasion loss which is determined by the Los Angeles Rattler Test Method should not exceed 40 percent. The swell test determines the amount of swell that occurs in a bituminous mixture in the presence of water. The stripping test gives an indication of the adherence of asphalt to the aggregate. The type of bitumen used with the aggregate has a considerable effect upon its resistance to stripping. From the results of the tests described above, definite sources of aggregates may be selected, or the number of potential sources materially reduced. These materials are then subjected to more detailed tests. Specimens containing various aggregate blends and various amounts of asphalt are compacted in four inch diameter molds by procedures which reproduce the density that is expected in the pavement after it reaches its maximum density under traffic. Specimens are prepared at a range of asphalt contents and tested for unit weight, Marshall Stability, and flow. The equipment used in determining the stability and flow is shown in Figure 5. The percent voids of the total mix and the percent voids filled with asphalt are computed from the unit weight and known specific gravities and percentages of aggregate, filler and asphalt. The results of the tests for each aggregate blend are plotted as curves of test properties versus asphalt content. Typical curves are shown in Figure 6. Optimum asphalt content is then selected for each aggregate blend as the average of the asphalt content at designated

points on the various curves. A job-mix formula is set up that meets the criteria established on the basis of laboratory and field investigations. The correct combination of materials is the key to obtaining a stable, workable, dense mix. Angular materials and crusher dust add stability to the mix while rounded natural sands supply workability. The binder or leveling course should be of a coarse texture with high stability. It should be designed for coarse aggregate interlock with sufficient fines and asphalt to bind the aggregate together into a mass where further consolidation will not take place. The surface course should be designed to contain the maximum permissible amount of asphalt which has a direct effect on durability, workability and resistance to damage from fuel spillage.

Concrete Testing for Design

General. Concrete used in pavements must have strength, durability and resistance to wear. Concrete having adequate strength generally exhibits satisfactory wearing qualities but not necessarily durability. The tests performed enable an evaluation of the properties of each of the constituents and of the finished product.[8] Corps of Engineers Specifications require that the flexural strength of the concrete be no less than a specified minimum at a designated age and the use of a low-alkali cement where reactive aggregates are used. Air-entraining admixtures are usually specified for all exposed concrete which will be subjected to freezing weather to improve its durability. Since air entrainment also improves workability and reduces bleeding of the fresh concrete, it is sometimes used in other pavements. However, a moderate reduction in strength is to be expected for air-entrained concrete.

Materials Survey and Acceptance Tests. A survey of economical aggregate sources to determine the availability of suitable quantities for construction of the pavement is made prior to the design of a paving mix. The materials normally required are coarse aggregate, fine aggregate, admixtures, water and portland cement or a blend of portland cement with slag or natural cement. Aggregates should be clean, hard, unweathered and uncoated. The usual tests performed on aggregates are sieve analysis, specific gravity and absorption, soundness, organic impurities, particle shape, soft particles, resistance to abrasion and petrographic analysis.

Requirements for the gradings of fine aggregates provide, in addition to the usual size limitations, a fineness modulus of not less than 2.3 nor more than 2.9. The coarse aggregate is furnished in two separate sizes to eliminate segregation during handling. Corps of Engineers Specifications do not usually contain a requirement for specific gravity or absorption. However, these values are determined since they are used in computing the mix proportions. Aggregates are tested for soundness by subjecting them to alternate periods of soaking in a solution of sodium or magnesium sulfate and drying in an oven under controlled conditions. They are acceptable provided the loss in 5 cycles does not exceed 10 percent for fine aggregate and 12 percent for coarse aggregate when sodium sulfate is used or 15 percent for fine aggregate and 18 percent for coarse aggregate when magnesium sulfate is used. Aggregates failing to meet this requirement may be used provided that comparable concrete made from similar aggregate from the same source can be shown to have given satisfactory service when exposed to weathering similar to that to be

8. Corps of Engineers Handbook for Concrete and Cement, Waterways Experiment Station, Vicksburg, Mississippi.

encountered. Soundness of aggregate is important especially in the Northern states where pavements are subjected to freezing while saturated with surface or subgrade moisture. Fine aggregates should be free of injurious amounts of organic matter. Aggregates tested in accordance with the standard ASTM Colorimetric Test which produce a color darker than the standard are rejected unless the standard mortar test indicates good quality or the discoloration is due principally to the presence of coal, lignite or similar discrete materials present in quantities within allowable limits. The shape of aggregate particles should be generally spherical or cubical. The percentage of flat and elongated particles in any size group of coarse aggregate should not exceed 20. Flat particles are particularly objectionable when they lie near the surface of the slab, since heavy loads may break them out and leave cavities in the concrete. A high resistance to wear is very desirable in aggregate to be used in pavement concrete. The Los Angeles Rattler Test produces qualitative data with respect to this property. Petrographic analysis indicates the presence of likely reactive minerals and the physical condition and the textural and structural characteristics of aggregates. The Standard Chemical Alkali-Reactivity Test and Mortar Bar Test are used to determine whether the reactive minerals are present in quantities sufficient to be harmful to concrete. The use of low-alkali cement is required where aggregates containing reactive minerals in harmful quantities are used in construction. Tests for clay lumps, soft particles and materials having specific gravities less than 2.0 are performed as indicated.

Water for washing aggregate and for mixing and curing concrete should be free from injurious amounts of oil, acid, salt, alkali, organic matter, or other deleterious substances. Water approved for domestic consumption can be used without being tested. Water of questionable quality is tested in accordance with AASHO Method T-26.[6] Admixtures, cements, curing compound, Kraft paper, joint sealers and dowel bars are tested in accordance with pertinent specifications.

Laboratory Design Testing. The design of concrete mixtures is the determination of the most economical and practical quantities of water, cement, aggregates and, in some cases, admixtures which, when combined and properly cured, will produce concrete having the desired strength, workability and durability. The stresses in a concrete pavement slab which control the design are the tensile stresses created by traffic loads and changes in temperature and moisture. The concrete is designed to have adequate beam strength and durability and with no more sand than is required to create a thin layer of mortar on the surface. The Corps of Engineers uses the water-cement ratio supplemented by trail mixes in the design of pavement mixes.

The proportions of the two sizes of coarse aggregate which most nearly approximate the desired grading are computed. The ratio of the volume of fine aggregate to that of total aggregate, and total water required for the desired workability and slump are determined by trial mixes. Both the nature and gradation of the aggregate affect the relative amounts of the different size materials that will give satisfactory workability with the least amount of water. After a thorough study of strengths obtained on similar materials and established water-cement ratio versus strength curves, mixes are prepared with four or more water-cement ratios that should produce flexural strengths both below and above the specified strength. Three or more standard 6" x 6" x 36" beams are fabricated from each mix, cured under standard conditions, and broken at designated ages. The specimens are loaded at the third point of an

18-inch span which permits two breaks from each beam. The equipment used in determining the flexural strength is illustrated in Figures 7 and 8. Figure 7 shows a portable beam breaker which is calibrated to indicate the flexural strength of 6" x 6" beams directly. Of course, corrections have to be applied when over or undersized beams are tested. Figure 8 presents a standard Universal testing machine. When this machine is used the flexural strength is computed from the total load at failure and the depth and width of the beam. The results of the tests are plotted as a curve of flexural strength versus water-cement ratio. A typical curve is shown in Figure 9. The mix design is prepared using the water-cement ratio indicated for the specified strength. The procedure for proportioning air-entraining concrete for a given flexural strength is the same as outlined above for non-air-entraining concrete. The air merely replaces a portion of the sand and mixing water.

Construction Control Testing

General. Frequently, construction operations will expose conditions of a degree and character not revealed by even the most carefully planned exploration and testing program conducted during the design phase. It is essential, therefore, that situations requiring special treatment be recognized so that appropriate action may be initiated. Control tests provide a means of establishing a record of significant properties of the materials involved for comparison with the provisions of applicable specifications and design criteria. The majority of these tests are performed at the site. Since testing facilities in the field are necessarily limited, representative samples are forwarded to the Division Laboratory, from time to time, for confirmation and record purposes, and for the performance of tests requiring more elaborate facilities.

Subgrade and Base Course Materials. Control of subgrade and base course materials involves determination of grain size distribution, plasticity characteristics, optimum moisture, maximum density, and actual density of compacted materials. Field CBR tests are performed on compacted bases for flexible pavements when these are composed solely of coarse, granular materials. Results are compared with those obtained during the primary investigation. Any important deviations form the basis for appropriate action.

Control of Bituminous Pavement Materials. In instances where aggregates obtained from the bins cannot be proportioned to reproduce satisfactorily the gradation used in the bituminous mix design, it is necessary to redesign the mix using plant produced aggregate. A sample of paving mix adequate for the preparation of four test specimens is obtained from each of the first four truckloads of paving mix upon initiation of plant production. Plant production is delayed until data from these tests are available. Proper adjustments are made to secure a satisfactory mix conforming to final design criteria. The average flow, voids, unit weight, and stability values should be in substantial agreement with flow and stability values from the final design. Once the plant has been placed in continuous operation, test specimens are prepared from only about every tenth truck load. A sample of paving mixture is obtained daily for extraction tests to determine the percentage of bitumen in the mix and the gradation of the extracted aggregate. Sufficient sieve analyses of samples of aggregate and mineral filler are made to determine conformance to specification requirements. Samples of asphalt are obtained from each car for acceptance tests. Samples for determining pavement density are obtained by a coring machine or by cutting out a section of pavement at least 6 inches square and

including the entire depth of the pavement. Four-inch diameter core samples are taken to determine stability and flow characteristics of the completed pavement. A minimum of two chunk or three core samples are obtained at the center and one edge of the runway at not more than 100 foot intervals. A sample consisting of a binder and surface course is split at the interface of these layers prior to testing. Stability, flow, and density determinations are made on each section of the core sample. The pavement should have a uniform density equivalent to 98 percent of laboratory compacted density for the surface course and 92 percent of theoretical maximum density for the binder course.

Concrete Paving Control Testing. In controlling the quality of concrete a number of field tests must be performed. These include gradation, surface moisture, organic impurities, slump, air content and test for objectionable fine material. Sufficient sieve analyses of samples of aggregate are made to determine conformance to specification requirements. The grading of the fine aggregate is controlled so that the fineness modulus of at least nine out of ten samples delivered to the mixer does not vary more than 0.20 from the average fineness modulus of the fine aggregate upon which concrete mixtures were designed. The free moisture tests on the aggregates are performed at least twice daily and whenever a significant change is apparent. Any standard procedure may be used in this test. The slump test is made whenever the appearance of the concrete indicates a change in consistency or whenever a routine inspection for record is required. A minimum of two tests should be made each day and more often at the beginning of a job or when aggregates are changed. Air tests by the pressure method are performed as often as required for adequate control and especially when a material change in water demand or consistency of the concrete is noted. Tests for objectionable fine material (Minus 200) are performed to determine conformance with the three percent maximum permissible for fine aggregate and one percent for coarse aggregate. Follow-up flexural strength tests are performed to determine the effectiveness of field control methods. These tests are made for the purposes of checking the laboratory strength design and determining when the pavement has acquired sufficient strength to be put in service. In the first case, the specimens are cured as nearly as possible under standard laboratory conditions, whereas, in the second case, the specimens are cured in as nearly as possible the same manner as the pavement. At the start of paving operations, flexural test beams are made as often as indicated but not oftener than one test group for each 40 cubic yards of concrete placed. Modification of the mix design will be made provided the average strength of the concrete obtained from tests on not less than 6 or more than 10 specimens departs from the desired minimum by more than 4 percent. After it has been established that the properties of the concrete being placed comply with the durability and strength requirements, specimens are obtained from each 300 cubic yards or less of concrete placed each day. A test group consisting of a minimum of two beams is taken from the concrete placed in designated areas to determine when the facility may be placed in operation.

Evaluation

General. Evaluation is the determination of carrying capacities of airfield pavement with respect to plane types, tire pressures, cycles of operation and pavement life. It begins, of course, in the design stage. Results of control tests form a basis for confirmation or modification. With time, however,

important changes may occur in such factors as subgrade moisture and density, concrete flexural strength, and asphalt stability. Evaluation programs are initiated to ascertain the effects of such changes, to establish more accurately a basis for future design, and in any case where required information is lacking or inadequate.

The first step in the evaluation is the study of existing data from previous tests made in connection with design, construction, and previous evaluations. Studies are also made to determine the performance of the pavements through traffic records, weather records, and the results of previous condition surveys. A review of these data, together with a current condition survey will generally enable a determination of the scope of the testing program required and the location of test areas. In some cases, the development of soil profiles is required. This is obtained by cutting or drilling small holes in the pavement and sampling base and subgrade materials.

Field Operations. Concrete pavements are cored with a 60 inch shot bit, or a comparable slab is removed by other means. Eight cores, four inches in diameter are recovered from each test location in asphalt pavements. A section of asphalt pavement approximately five feet square is then removed. Plate bearing tests are performed on the soil underlying rigid pavements and Field CBR tests are performed on that underlying flexible pavements. The latter must be performed for each full six inch thickness of base and sub-base and on the surface of the subgrade. Density determinations are made in connection with each plate bearing and CBR test. Except for cohesionless or saturated subgrades, or where pavements have been in place for more than five years, undisturbed samples are obtained for the determination of strength changes with increase in moisture. Larger quantities of representative soils are also obtained.

Soils Testing. Classification and compaction tests are performed on representative soil types. Consolidation and/or CBR tests (depending on whether rigid or flexible pavement or an overlay is involved) are performed at field moisture and in the soaked condition to determine the changes in strength which may be expected due to increase in moisture content.

Bituminous Testing. The pavement cores are tested for density, stability, and flow. Extraction tests are performed on the chunk samples for the determination of asphalt content and aggregate gradation. Standard specimens are recompacted from the chunk samples and tested for density, stability and flow. The percent voids total mix and voids filled with asphalt are computed. When more than one course is involved, the above tests are performed on each course. A sufficient quantity of the asphalt is recovered to test for specific gravity, ductility, and penetration.

Concrete Testing. The concrete cores are sawed into 6" x 6" beams and tested for flexural strength as described under concrete mix design.

Evaluation. These data are assembled and presented in considerable detail because they may be used in certain research studies to improve design criteria and because continuing aircraft development may necessitate evaluations for other types of landing gear assemblies as well as those now in general use. The final values used in arriving at the load-carrying capacity are given with an adequate discussion of the reasons for their selection. The evaluation of an airfield as a whole is based on the carrying capacity of the weakest facility that is necessary to keep the field completely operational. A complete discussion of the factors considered in determining the controlling facility is presented in the report.

CONCLUSION

The investigational and testing programs outlined above insure the design and construction of safe and economical pavements and provide documentary evidence of the quality of materials incorporated therein. These data, together with performance records and results of large scale traffic tests, provide an ever-increasing body of knowledge concerning behavior of pavements under the stress conditions imposed by heavy airplace traffic. Continuous review and evaluation of these data permits the development of more economical design criteria and the construction of better pavement.

FIG. 1 UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 inches and basing fractions on estimated weights)		
1	2		3	4	5		
Coarse-grained Soils: More than half of material is larger than No. 200 sieve size.	Gravels: More than half of coarse fraction is larger than No. 4 sieve size.	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below). [4]		
	Sands: More than half of coarse fraction is smaller than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.		
			SP	Poorly-graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
Fine-grained Soils: More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size		
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)
	Silts and Clays: Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight
	Silts and Clays: Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.		

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols.

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (Reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

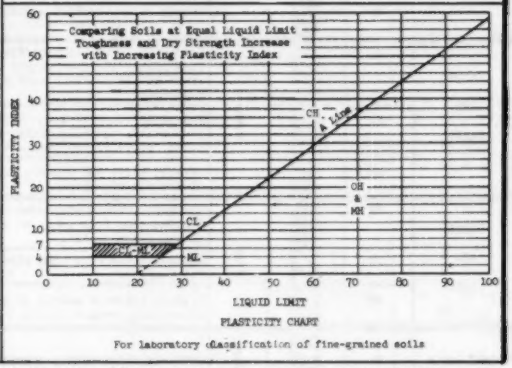
Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Information Required for Describing Soils	Laboratory Classification Criteria
6	7
For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics. Give typical name; indicate approximate percentages of sand and gravel, max. size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).	Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5% — GW, GP, SW, SP; More than 12% — GM, GC, SM, SC; 5% to 12% — Borderline cases requiring use of dual symbols. $C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3 Not meeting all gradation requirements for GW Atterberg limits below "A" line or PI less than 4 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols. Atterberg limits above "A" line with PI greater than 7 $C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3 Not meeting all gradation requirements for SW Atterberg limits below "A" line or PI less than 4 — Limits plotting in hatched zone with PI between 4 and 7 are borderline cases requiring use of dual symbols. Atterberg limits above "A" line with PI greater than 7
Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parentheses. For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. Example: Clayey silt, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML).	Use grain-size curve in identifying the fractions as given under field identification.



PLASTICITY CHART

For laboratory classification of fine-grained soils

For example GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. standard.

Toughness (Consistency near plastic limit)

After removing particles larger than the No. 40 sieve size, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

FIG. 2 CHARACTERISTICS PERTINENT TO

Major Divisions (1)	(2)	Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value as Foundation When Not Subject to Frost Action (7)	Value as Base Directly under Bituminous Pavement (8)
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Good
		GP			Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Poor to fair
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Fair to good
		GM u				Good	Poor
		GC			Clayey gravels, gravel-sand-clay mixtures	Good	Poor
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Poor
		SP			Poorly graded sands or gravelly sands, little or no fines	Fair to good	Poor to not suitable
		SM d		Yellow	Silty sands, sand-silt mixtures	Good	Poor
		SM u				Fair to good	Not suitable
		SC			Clayey sands; sand-clay mixtures	Fair to good	Not suitable
FINE GRAINED SOILS	SILTS AND CLAYS LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Fair to poor	Not suitable
		CL			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Fair to poor	Not suitable
		OL			Organic silts and organic silt-clays of low plasticity	Poor	Not suitable
	SILTS AND CLAYS LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable
		CH			Inorganic clays of high plasticity, fat clays	Poor to very poor	Not suitable
		OH			Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not suitable	Not suitable

Notes:

1. Column 3, Division of GM, and SM groups into subdivisions of d and u are for roads and airfields only; subdivision is on plasticity index is 6 or less; the suffix u will be used when the liquid limit is greater than 28.
2. Column 7, values are for subgrades and base courses except for base course directly under bituminous pavement.
3. In column 8, the term "excellent" has been reserved for base materials consisting of high quality processed crushed stone.
4. In column 9, these soils are susceptible to frost as indicated under conditions favorable to frost action described in the
5. In column 12, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture are listed, because variable soil characteristics within a given soil group may require different equipment. In some
   a. Processed base materials and other angular materials. Steel-wheeled rollers are recommended for hard angular materials to degradation.
   b. Finishing. Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed
   c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield
      Crawler-type tractor -- total weight in excess of 30,000 lb.
      Rubber-tired equipment -- wheel load in excess of 15,000 lb, wheel loads as high as 40,000 lb may be necessary to obtain
      Sheepsfoot roller -- unit pressure (on 6- to 12-sq-in. foot) to be in excess of 250 psi and unit pressures as high as should be at least 5 per cent of the total peripheral area of the drum, using the diameter measured to the faces of
6. Column 13, unit dry weights are for compacted soil at optimum moisture content for modified AASHO compactive effort.

Potential Frost Action (9)	Compressibility and Expansion (10)	Drainage Characteristics (11)	Compaction Equipment (12)	Unit Dry Weight Lb Per Cu Ft (13)	Field CBR (14)	Subgrade Modulus k_g Lb Per Cu In. (15)
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	125-140	60-80	300 or more
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	110-130	25-60	300 or more
Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller; close control of moisture	130-145	40-80	300 or more
Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200 to 300
Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200-to 300
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	110-130	20-40	200 to 300
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100-120	10-25	200 to 300
Slight to high	Very slight	Fair to poor	Rubber-tired equipment sheepsfoot roller; close control of moisture	120-135	20-40	200 to 300
Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20	200 to 300
Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20	200 to 300
Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller; close control of moisture	100-125	5-15	100 to 200
Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100-125	5-15	100 to 200
Medium to high	Medium to high	Poor	Rubber-tired equipment, sheepsfoot roller	90-105	4-8	100 to 200
Medium to very high	High	Fair to poor	Sheepsfoot roller	80-100	4-8	100 to 200
Medium	High	Practically impervious	Sheepsfoot roller	90-110	3-5	50 to 100
Medium	High	Practically impervious	Sheepsfoot roller	80-105	3-5	50 to 100
Slight	Very high	Fair to poor	Compaction not practical	-	-	-

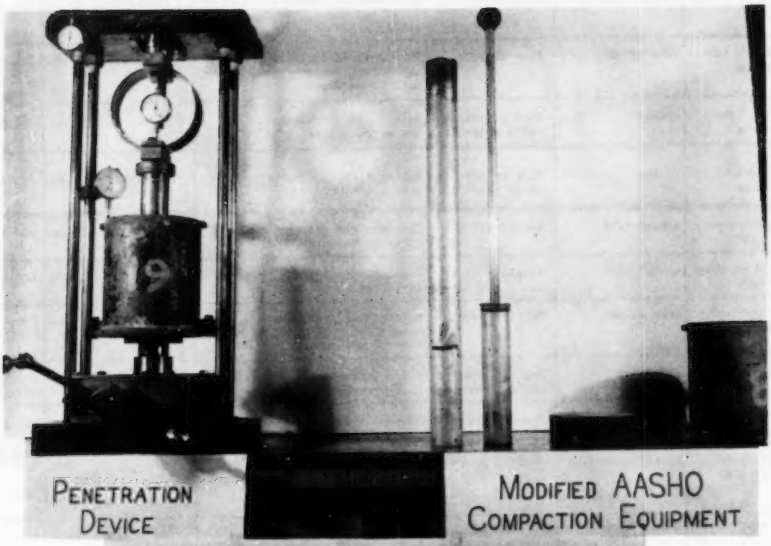
basis of Atterberg limits; suffix d (e. g., GMd) will be used when the liquid limit is 28 or less and the

text.

conditions and thickness of lift are properly controlled. In some instances, several types of equipment
instances, a combination of two types may be necessary.
with limited fines or screenings. Rubber-tired equipment is recommended for softer materials subject

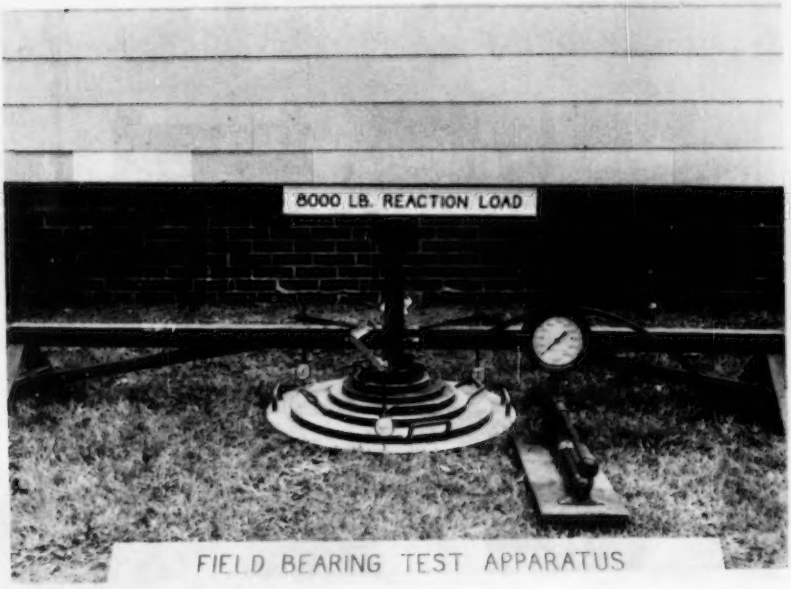
materials.
construction:

the required densities for some materials (based on contact pressure of approximately 65 to 150 psi).
050 psi may be necessary to obtain the required densities for some materials. The area of the feet
the feet.



CALIFORNIA BEARING RATIO

FIG. 3



FIELD BEARING TEST APPARATUS

FIG. 4

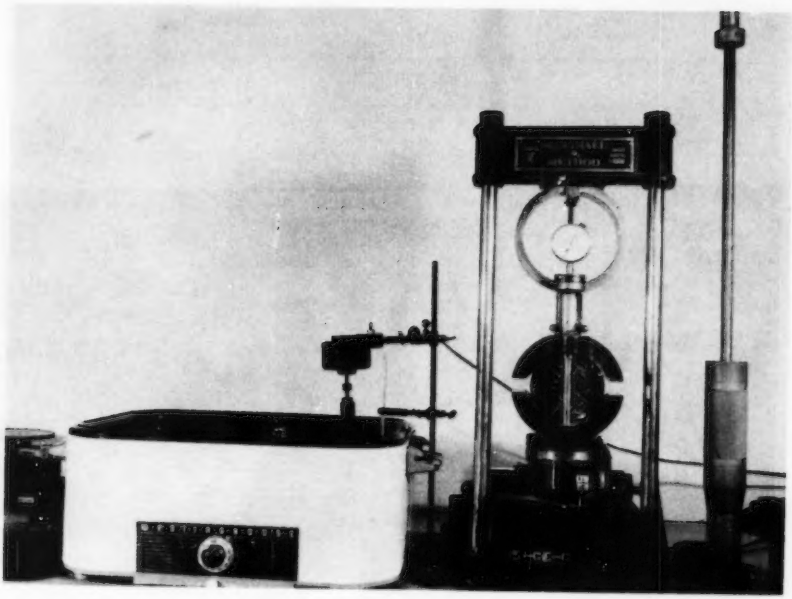
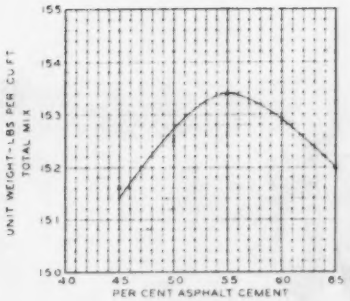
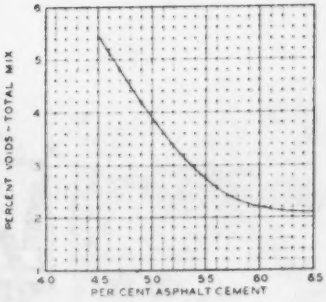
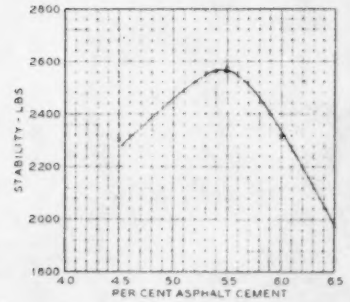
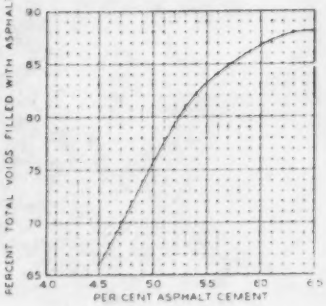


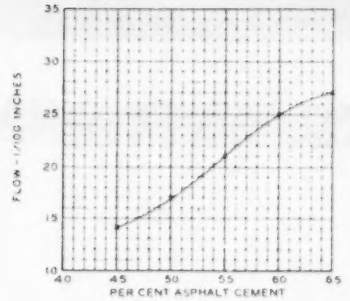
FIG. 3 - MARSHALL STABILITY TEST EQUIPMENT











ASPHALT PAVING MIX DESIGN		
JOB NO. 182	PROJECT NO. TYPICAL MIX	DATE 24 AUG 1950
DESCRIPTION OF BLEND: 40% SAMPLE NO. 7328, 52% SAMPLE NO. 7334, 8% SAMPLE NO. 6814 ASPHALT CEMENT NO. 6673		
PLOTTED BY D.P.B.	CHECKED BY T.W.G.	

FIG. 6

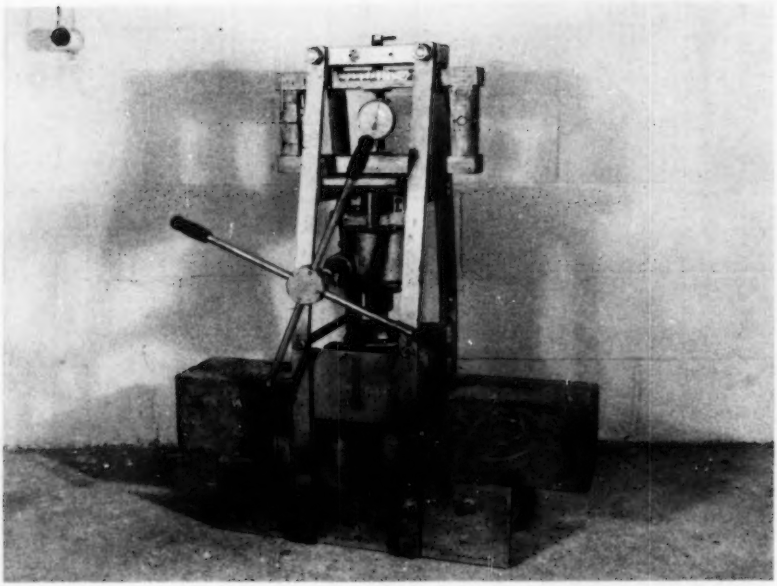


FIG. 7 - PORTABLE CONCRETE BEAM TESTER FOR DETERMINATION OF FLEXURAL STRENGTH.

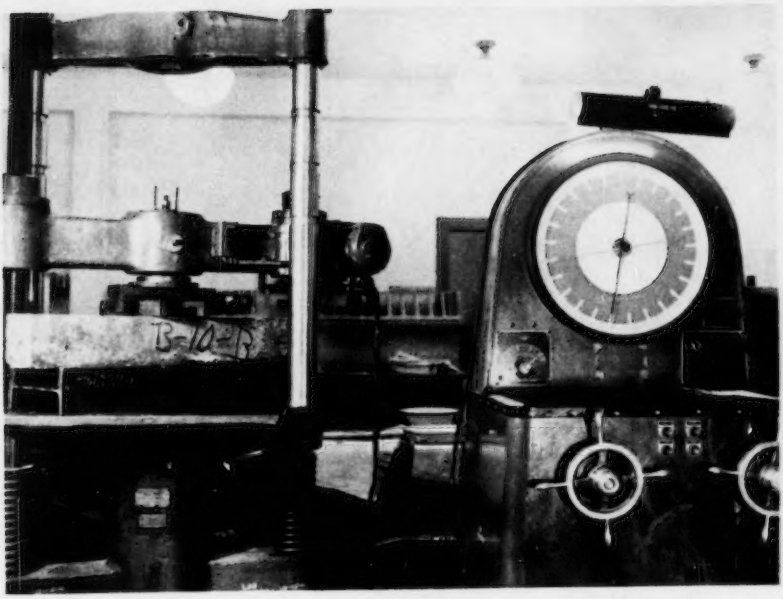
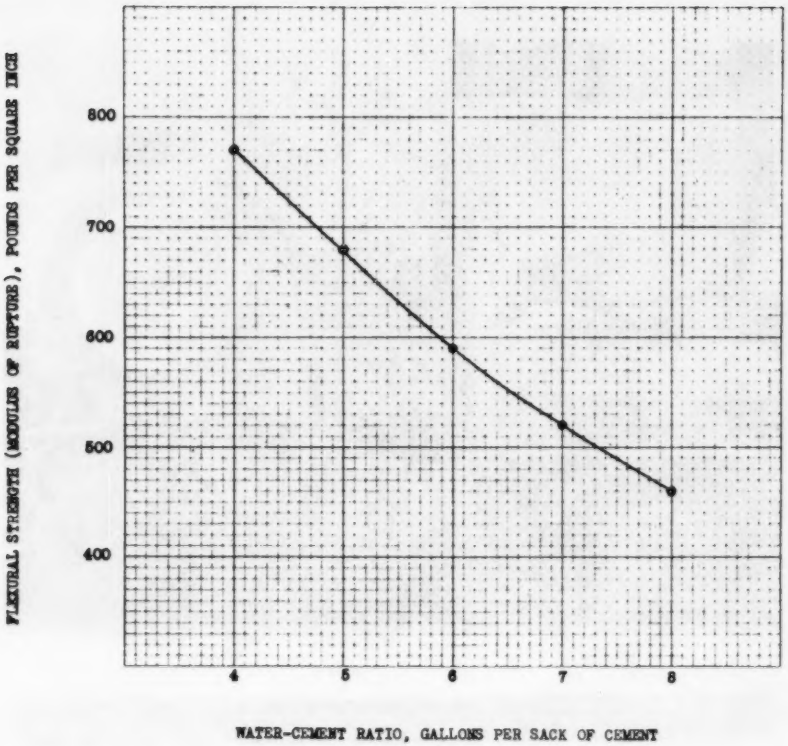


FIG. 8 - UNIVERSAL TESTING MACHINE ARRANGED FOR THE DETERMINATION OF FLEXURAL STRENGTH OF CONCRETE BEAMS



TYPICAL RELATIONSHIP OF FLEXURAL STRENGTH
(MODULUS OF RUPTURE) TO WATER-CEMENT RATIO

FIG.-9